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by R. Auffret and H. Seris

AGARD Collected Papers Presented at the
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MEDICO-PHYSIOLOGICAL INCIDENCES ON THE PILOT FOR FLIGHT PATTERNS TYPICAL OF VTOL

R. Auffret and H. Seris

The mechanical complexity of VTOL operation is assessed, and it is pointed out that the procedures developed for low speed flight pose new problems for the pilot. These are in addition to such difficulties as the altitude and speed encountered in normal high performance aircraft, and the various phases of takeoff, transition, and landing on a pinpoint location. With specific reference to medico-physiological demands on the pilot it is indicated that in the VTOL there is little danger of contamination of the cabin from exhaust gases, and that most missions can be flown without oxygen mask, but that such apparatus must be available for high altitudes and for certain special requirements. Low frequency vibrations are not regarded as a potential hazard since their occurrence in the tested VTOLs was brief. It is recommended that emergency ejection be effected through the windshield at low altitudes: statistics are quoted which indicate that damage from the shattered glass is not a major factor.

1. Introduction

The advent of VTOL aircraft is bound to two strategic imperatives that /247* are difficult to reconcile.

The requirement of high speed in flight in order to be able to escape detection and enemy attack, and the vulnerability of the airstrips, whose length has increased as a function of the speed and weight of the craft are the two imperatives in question.

Length of the airstrip that is necessary for the dispatch and landing of a standard high performance airplane is essentially a function of the minimum speed of control, which itself is increasing with the new aerodynamic configurations. To decrease this speed which is slightly greater than the speed of free flight, special high-lift flaps, swept wings, variable-geometry wings are used. To attain free flight more rapidly, supplementary rocket engines can be supplied. To diminish the braking distance, special systems can be used, such as brake parachutes but all this only affords limited solutions. The paved concrete runways more than 2 km long needed by Mirage III which, let us remember, cleared the landing field lights at a speed of more than 160 kts, were very vulnerable to fighter bomber attack with standard explosives. The miniaturization of nuclear projectiles would make it possible to knock them out rapidly. The survival of aviation in case of nuclear conflict rests on the possibility of scattering into the countryside. Thus the classic airbase must be completely abandoned, and operational units must be established that comprise a limited number of planes accompanied by servicing elements, the whole dispersed and camouflaged. The airplane that can be used in missions of this kind must be capable of pinpoint takeoff and landing, just like a helicopter, with a speed greater than Mach 2.

*Numbers given in margin indicate pagination in original foreign text.

The VTOL formula constitutes the answer to these two requirements, but it entails great mechanical complexity and very precise manual piloting. Although the pilot is confronted in high speed flight by piloting difficulties that are characteristic of high performance planes, the takeoff, landing and transition phases cannot be equated with the maneuvering conditions of a helicopter. Original solutions have had to be thought through on this account.

Because of the speeds required of the plane, only jet propulsion can be considered. This is why the French version took as a point of departure the most recent Mach 2 plane, the Mirage III.

On the Mirage III.V high-speed horizontal flight is thus controlled like /248
that of a conventional machine by means of a standard piloting system consisting of stick, hydraulic servo and control surfaces. The speed on trajectory is ensured by a post-combustion horizontal rocket engine whose thrust is controlled by a gas valve.

In very slow or steady flight, lift is ensured by 8 vertical-thrust jets controlled by a second gas valve. Since the ordinary control surfaces are inadequate in this configuration, for moments of yawing, roll, etc., it has been indispensable to add piloting compressed air jets to them (fig. 1).

VTOL nevertheless remains an aircraft without inherent stability.

The pilot must be regarded as one of the elements of the closed loop that ensures flight control (fig. 2).

According to this block diagram, the pilot receives two kinds of visual data:

- imprecise and sometimes erroneous external vision
- data coming from different control apparatus concerning the position of the craft and its motor functioning.

By integrating these data, the pilot decides upon and then executes a movement of command. The loop closes for the first time on the pilot, since he has a kinesthetic sensation of movement effected, and in addition a sensation of effort proportional to the amplitude of the movement, by way of a box of springs still called the "effort simulator box". The command in its turn actuates the servo that acts on the control surfaces. There is a return path from the servo toward the data in the form of all-or-nothing quantitative or qualitative signals from the breakdown indicator.

From the control surface actuated by the servo we return via the aircraft movements to the two primary data of external visibility and the instrument panel.

We thus think of the pilot's job in the loop by dividing it into two parts: data and action.

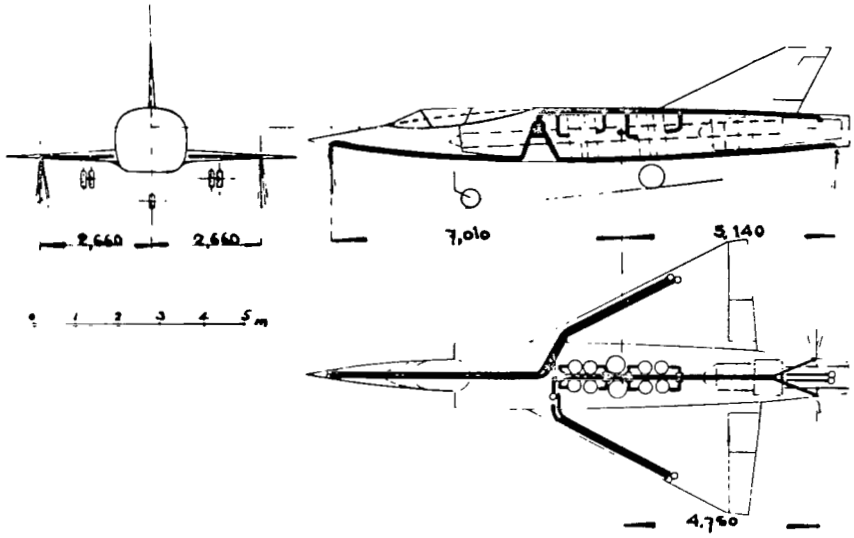

Figure 1. Air jet controls of the Balzac V. 001

2. Data Presentation on the Instrument Panel

As far as data are concerned, let us say at once that external visibility, though it is certainly very important, must always be suspect. It can also be lacking, because we have to bear in mind that the missions of the craft must be as independent of weather conditions as possible.

Insofar as there is possibility of erroneous interpretation, let us take an example:

- a VTOL plane in steady flight above a fixed ground point in a 30-kt crosswind will seem to the pilot to be motionless, whereas he will be in a slip, which is very dangerous.

The instrument panel gives the pilot more precise data. They should be of /249
two kinds: motor function and position of the plane on the three axes (and altitude).

The octuple thrust indicator (fig. 3) comprises eight vertical scales, one per engine, reproducing the pressure ahead of the compressor transmitted by eight pressure sensors. The pilot thus has at a single glance an exact picture of the essential lift parameter. Because of the linear arrangement adopted for the indicator needles, the slightest malfunction of an engine is seen at a glance. Eight luminous signals are at the periphery: if the nozzle temperature of a jet engine exceeds a predetermined value, the corresponding signal lights up, and by pressing the signal button the pilot cuts off the engine.

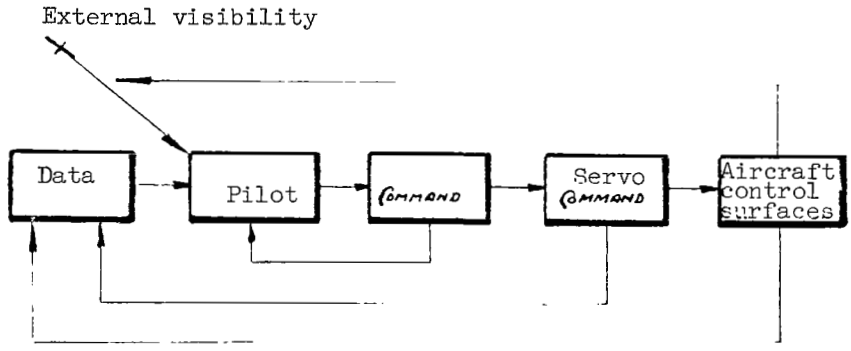

Figure 2. Block diagram of the closed loop at piloting.

To present the same totality of data, 16 instruments with circular dials would have been required, plus 8 engine cutoff control levers.

The flight control (fig. 4) is an answer to the need to concentrate the signals and piloting commands in the most accessible region of the instrument panel for handling flight and mission situations as follows:

a) vertical takeoff and landing with good visibility, with or without radar assistance;

b) vertical takeoff and landing with poor visibility, with or without radar assistance;

c) very low altitude flight without visibility

d) navigation with or without visibility

e) blind firing and bombardment

Let us take a quick look at the data furnished to the pilot (seems to have been using a pointer to refer to Figure 4: trsl.)

- At the center, a ball-type indicator gives yaw, pitch and head.
- To the right, an instantaneous vertical speed indicator
  - an altitude indicator: data obtained by radioaltimeter
- To the left, an attitude indicator
  - a speed indicator capable of receiving velocity indications during the transition phase

- ground speed

- Above: transverse speed during vertical flight.

The indicators are ribbon instruments, which improves the reading precision, in spite of the small dimensions. Reading is done opposite a fixed central reference mark.

This instrument (flight synthesizer of figure 4: trsl.), placed in a privileged zone of vision, is consulted very frequently. It gives the pilot a complete picture of his situation in space as far as position and speed are concerned, and affords him the opportunity to plan actions to be effected.

This instrument can also give orders to the pilot if he is connected with /250
the radioelectric apparatus on the ground or with the onboard navigation system.

We have limited ourselves to the description of two original instruments that are sufficient to give the pilot all the necessary data. The plane is additionally equipped with all the standard controls that may be useful in case of partial or total failure of the synthesizer.

As a matter of fact, these novel instruments (synthesizer, ribbon instruments) do not at present have an adequate coefficient of reliability to be used alone. On test planes it is necessary for the moment to back them up with conventional controls, which complicates the test pilots' job.

In his character as a loop element, the pilot must be regarded as a computer. He receives data from various sources. The synthesis furnishes him the picture of the situation. Comparing this picture with the elements that he has in his memory, he works out his commands.

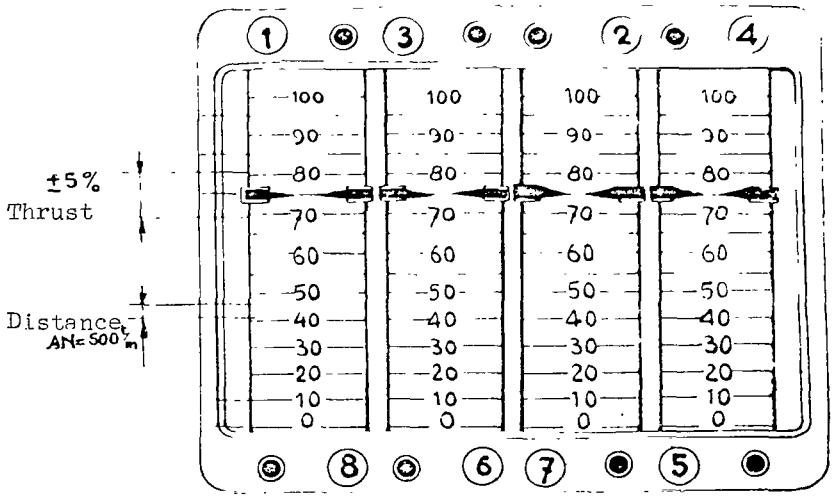

Figure 3. Octuple thrust indicator.

3. Aircraft Controls

To transmit his commands, the pilot has at his disposal the conventional controls: stick, control surface, gas valve for the horizontal jet engine, plus control valve for the lift jets. For the latter there is a single valve that acts on the adjustment of each of the jets.

In figure 5 we present the block diagram of the elevator control.

The stick movement is transmitted via a hydraulic servo control to the system that mechanically drives the control surface in normal flight. For the sake of safety, we point out that the servo is covered by the comparator breakdown detector.

For steady flight the steering movements are electrically repeated on a triple detector. Two refer to an electric servo control that also picks up the movements of the valve control and angular velocities of the aircraft as furnished by the gyrometer. The amplifier output actuates the motor of the hydraulic servo valve that actuates the control surfaces.

The third detector operates an identical measurement circuit but has no effect on the control surfaces.

The indicators of these 3 circuits are compared in a breakdown detector that automatically releases the valve of the faulty circuit. Naturally the signal lights up on the instrument panel, to inform the pilot that the circuit is defective.

In case of total failure of the servo control the system locks onto direct manual control.

The output of the servo control actuates the valves that regulate admission of compressed air into the piloting nozzles. /251

4. Comparison With the Piloting of Other Airplanes

What is the relationship between the order of command, reaction on the control surface and movement of the aircraft? In an ordinary plane, in order for example to bank, a lateral displacement of the stick in question brings about a given deflection of the aileron which defines a constant rate of bank throughout the whole maneuver.

We might say therefore that this is attitude piloting.

Piloting by means of air jets has very different characteristics.

Let us represent the effect of a displacement of a control surface by an angle alpha as a function of time. The nozzle will open by an angle $T\alpha$ and the angular velocity of the plane will start to increase (fig. 6). As long as the nozzle is open, the angular velocity will increase, which makes piloting particularly difficult because of the resultant instability.

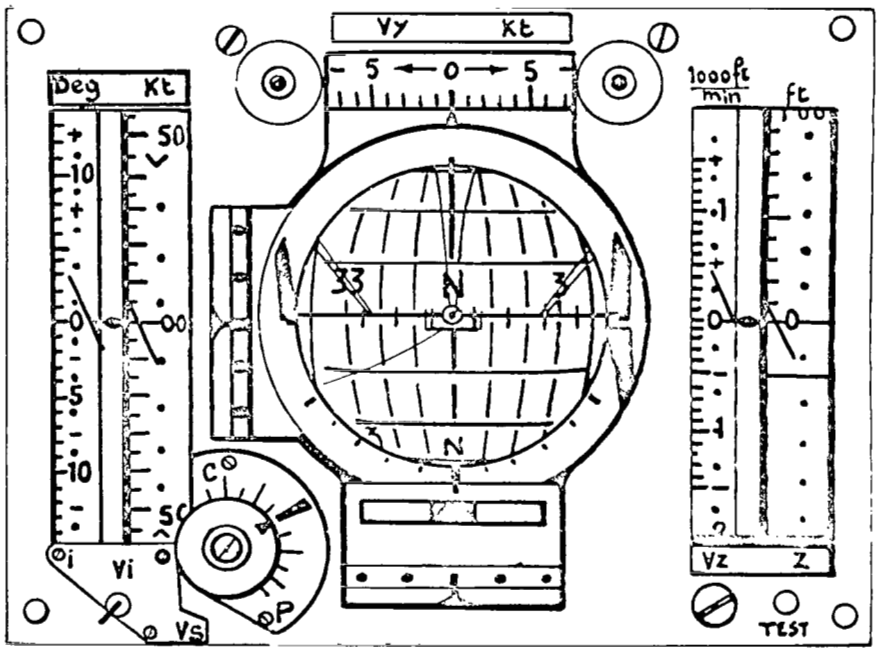

Figure 4. Flight synthesizer.

This is why the angular velocity as determined by gyrometer is a component in the piloting system.

We observe in figure 6 that when the selected maximum angular velocity is reached, the nozzle is closed, even though deflection of the control surface is maintained.

The nozzle equation is

$$T\alpha = S\alpha + \Delta\rho$$

in which T is the opening of the nozzle as a function of the pilot's command and ρ is the angular velocity of the craft. The terms S and A are factors of proportionality selected by the pilot.

At the start, ρ was zero or very low and the nozzle was widely open as a function of the command. When the value of ρ became large, order α became negligible entailing closure of the nozzle.

Because of this, damping will be more important for slight deflections, which is a stability factor.

We see that in this case we may speak of acceleration piloting.

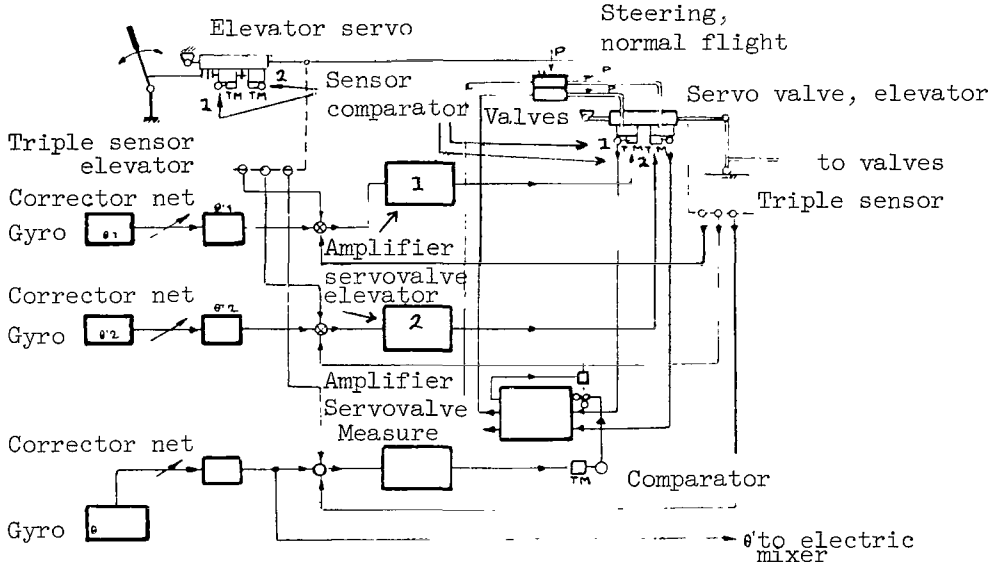

Figure 5. Block diagram of elevator control.

The response time of the servo system is of the order of 1/10 second.

The response of the plane is governed by its own equations, and its variable as a function of the order received. We have to abandon the idea of writing the transfer function of the pilot precisely, because his response time, though it is on the average of the order of 30/100 second, can vary as a function of individual reaction time of the moment in the same individual.

Summing up, it is in the phases of transition and especially in the return /252
transition before landing that the pilot's work load is considerable. At this time the piloting must be very accurate, to follow a well determined path with given parameters (speed and altitude). The correct inclination is difficult to establish. In less than 3 minutes the pilot must execute about ten maneuvers, make about twenty checks at different locations in the cabin, some of which are of major importance. In the course of this interval the fuel consumption is very important, imposing a very strict limitation because the fuel reserves admitted are minimal. In the last part, to go from steady flight to ground he must continually look outside while at the same time keeping an eye on the variometer which indicates the level of descent, approximately 300 feet/minute, and the pilot sees the ground "climb very fast" and he must almost "kick himself" to make impact at this rate of descent.

No visual or kinesthetic sensation ("flying by the seat of the pants") indicates the imminence of a slip that takes the plane out of control, and the pilot has to submit blindly to the indications of the luminous arrows.

Actuating the controls induces excellent responses in attitude, but the corrections are rather slowly established, much more so than in the case of the helicopter, for example. This inertia surprises the pilots in their first flights. In short, the important work required in this transition phase has been able to make a test pilot forget the most elementary check of all: check the green lights that indicate that "the train has left the station."

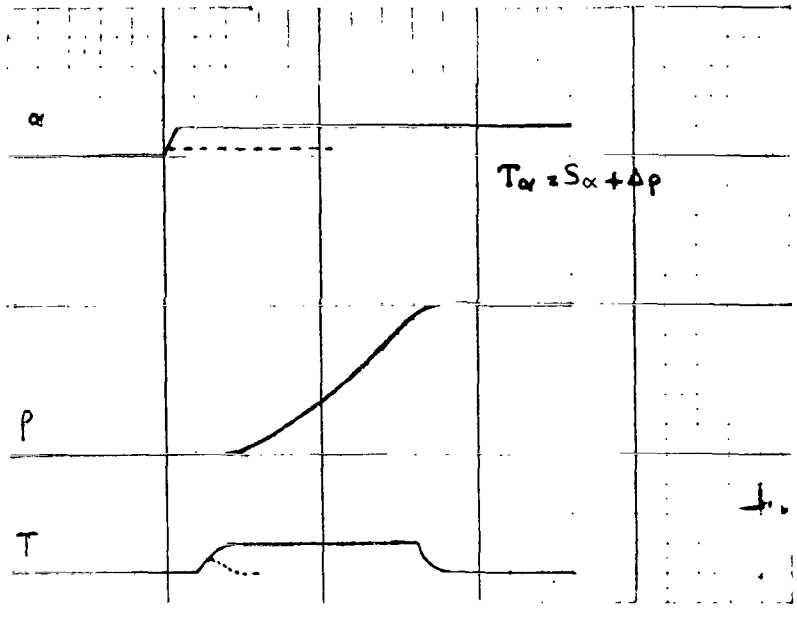

Figure 6. Response nozzle and plane to a control action.

5. Exhaust Gases

In landing, takeoff, transition, the abundance of exhaust gases in the atmosphere around the plane has involved risks of contaminating the air in the cabin. In flight trials of the French prototypes no toxic dose was found in the pilot's compartment.

The speed of these flight phases and the relatively good seal of the cabin has made it possible to execute many flights without oxygen inhalation, which puts the pilot in the best conditions of comfort, "shirt-sleeve flying."

Nevertheless the VTOLs are intended for occasional high altitude missions and they must be equipped with miniature oxygen inhalators that can dispense O_2 in dilution or up to 100% at ordinary pressure or even at slight excess pressure.

Besides, certain types of flight (patrol, night) and certain conditions (running behind another plane, denitrogenation) will always require the presence of the O_2 inhalator system. There would be no question of taking chances with VTOL pilots.

6. Vibrations

Do low frequency vibrations (structural vibration, turbulence, instability of the plane) encountered in takeoff, landing and transition phases complicate the pilot's job? Flight tests have shown that the buffeting encountered in transition lasted a few seconds and could not be bothersome. Upon takeoff with lift jets at full load, vibrations and noise were intense only in the first 2 or 3 meters. By the "holdback" technique and takeoff on the shock absorbers the /253 duration of this phase is held to a minimum.

7. Pilot Bailout

The USAF statistics indicate a level of mortality of 63% for ejections at an altitude below 500 feet for the following reasons: "Too low altitude" or "Delayed ejection." It is necessary therefore to rethink the matter of pilot bailout in the case of low altitude, trying to reduce the duration of ejection.

In steady flight or in transition phases the slight relative wind does not promote ejection of the windshield. Also the passage of seat and pilot through the windshield in this situation seems to be the sole possible method of evacuation. There is advantage in eliminating the sequence of release of the windshield to reduce ejection time by one second. The importance of this one second gain has already been verified in several accident cases.

Ejection through the windshield, moreover, allows the pilot to know his position at the instant that he triggers the various sequences. In fact, when control of the airplane is lost, the high speeds of roll that are encountered do not allow the pilot to know his position from one second to the next. Furthermore the elimination of the windshield ejection mechanism which is necessarily heavy, involves a weight saving that is not inconsiderable, an interesting argument for the builders.

In brief, the absence of relative air current, the high roll speeds when control is lost, the need for time saving, are all arguments for ejection through the windshield. But does this not entail risk to the pilot?

To answer this question, the CEV ran a series of 20 experimental ejections through the Etendard IV.M, Balzac V and Mirage III.V windshields at Bretigny, using dummies and Martin-Baker AM4 and AM6 standard seats.

These experiments made possible a set of precise measurements indicating the physiological consequences of ejection of a human dummy (acceleration, vertebral compression, shock) and the determination of minor modifications that would allow improvement of the shattering of the windshield and passage of the

seat: cutting knives, protection of the head casing, seat, limit thickness of the glass.

This experiment can be compared with accidental or deliberate human ejection through the windshield. The various British or American statistics prove that there are no significant lesions caused by shattering the windshield, particularly at low speed.

Out of 31 ejections through the windshield with Martin Baker seats in 1964, 14 subjects were uninjured, 9 were slightly hurt, 5 were seriously injured and 3 died. Of these 17 dead or seriously injured (sic) only two subjects were observed who presented muscular tears at the knee level that could be attributed to the windshield.

Ejection of this type has already saved the lives of several VTOL pilots in /254 the low altitude phase, and it can be said that for the Balzac V or Mirage III.V ejection through the windshield does not entail serious risks for the pilot.

8. Conclusions

Experience acquired in test flights of various prototypes makes it possible to hope for valuable compromises or even happy solutions of the various difficulties encountered.

However we feel that operational missions intended for the VTOLs (penetration at high speed and low altitude) are in themselves matters of very precise execution. The human brain does not have time to coordinate the data furnished by external observation and by the instruments to ensure simultaneously the piloting, navigation and the mission. To avoid this saturation, the pilot needs a great number of automatic aids, plane controlled by an automatic pilot, for example, but it is up to the human pilot to choose the program and supervise its execution.

We have justified the need for the presence on board the plane of all these radars, automatic pilots, computers and servos: it might well be asked if it is then absolutely necessary to leave the pilot on board. His performance is mediocre, his very slow reaction time entails inaccuracy, even instability. His characteristics are not dependable, his endurance is short, his memory is scanty and fallible. This poor tool does not even offer the advantage of sturdiness: his temperature must be controlled within a few degrees, he must have oxygen, and in case of accident his rescue as we have seen presents very difficult problem.

Let us not forget, however, that unwise automation comes to a dead end. The chances of failure can be reduced by multiplication of the circuits, but a percentage remains that requires the intervention of a system endowed with judgment, which is to say a man, who will also be indispensible if the program is to be altered in the course of a mission.

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